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MANUAL OF RECOMMENDED WATER-SANITATION PRACTICE RECOMMENDED BY THE PUBLIC HEALTH SERVICE

Public Health Service
Cincinnati, Ohio

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U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE

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INTRODUCTION

This Manual of Recommended Water-Sanitation Practice was prepared cooperatively by the Water and Sanitation Investigations Station, Cincinnati, Ohio, and the Sanitary Engineering Division, United States Public Health Service.

A technical committee of Public Health Service officers wrote this manual which, primarily, is to serve as a guide to Public Health Service engineers in evaluating the sanitary features of water supplies with which they are concerned. It has been made generally available because it is felt that this type of manual is useful also to State departments of health and others concerned with water sanitation.

This manual is intended only to represent the recommendations of the committee and to present certain practices and procedures which the committee believe will be helpful in the field of water sanitation. These recommended procedures and practices are not to be interpreted as mandatory requirements, nor are they intended to exclude other practices and procedures. The fact that a certain practice may not be followed or that other practices may be substituted shall not of itself be considered as a failure to attain adequate water sanitation.

The text of this manual is divided into four sections. In outline form, part I gives those features of water-supply systems which are of sufficient importance to be included in a sanitary survey, and lists major sanitary defects and health hazards, which, if present, would be detrimental to the safety of the water supply. Parts II and III deal, respectively, with recommended sanitary requirements for water treatment and for water-distribution systems. These two parts of the manual are in the form of a connected discussion, amplifying the outline material given in part I.

Part IV has been added as an explanatory discussion of the bacteriological and chemical requirements for potable drinking water as set forth by the 1946 Public Health Service Drinking Water Standards (*1*).

In preparing this manual, full advantage has been taken of the criticisms of the earlier text, which appeared as a part of Reprint No. 2440 from the Public Health Reports (*1*). It has been prepared by various members of the Advisory Committee which prepared the 1942 and 1946 Public Health Service Drinking Water Standards, several State sanitary engineers, and others. Although it was obviously impossible to reconcile fully the conflicting views of any group as large as the one consulted, an

effort has been made to follow the consensus of a representative majority of the group. The authors of this manual acknowledge gratefully the many helpful comments which have been furnished by members of the advisory committee, State sanitary engineers, and other individuals on the material herein presented.

PART I

PHYSICAL FEATURES OF WATER-SUPPLY SYSTEMS AND THEIR SANITARY PROTECTION

According to the Public Health Service Drinking Water Standards definition, a "water supply system includes the works and auxiliaries for collection, treatment, and distribution of the water from the source of supply to the free-flowing outlet of the ultimate consumer." Sanitary protection is concerned with all those parts of a water system which come within this definition, though for practical purposes attention may be concentrated mainly on those parts which have to do with the sources, treatment and distribution of the water.

SCOPE OF REQUISITE INFORMATION AS TO SOURCE AND PROTECTION

In order that persons concerned with the sanitation of water supplies may have the necessary information upon which to base an opinion concerning a water supply and to make recommendations, it is requisite that each water supply coming under consideration should be carefully studied with reference to its source and protection. The precise scope of such a study and of the report thereon will vary according to the circumstances existing in each individual case and cannot be fully specified in any general terms. The general procedure should be substantially as follows:

1. A sanitary survey of the water supply should be made by a competent person. The reliability of the data collected will depend largely upon the competence of the person by whom the survey is made. Hence, the careful selection of personnel for this duty is of primary importance. The qualifications which constitute "competence" cannot be precisely defined. In general, the person making the survey should have received a technical education in the basic sanitary sciences equivalent to that given in a course in sanitary engineering in a recognized college of engineering or school of public health. He should have a broad knowledge of

the sanitary features and physical facts concerning potable water supplies and their sources, and should understand the essential features of water-purification plants and systems, their operation, and proper methods of laboratory control.

2. A brief general description of the water supply should be submitted. This should include:

a. The name of the owner of the supply.

b. A brief description of sources and catchment areas.

c. A brief description of the storage available both prior to and following treatment.

d. A brief description of the plant, including the date of installation of the main works, and a record of subsequent extensions or alterations.

3. A partial summary of the pertinent facts relating to the sanitary condition of the water supply, as revealed by the field survey, should be submitted. The following outline will serve to indicate the general scope of a survey. Not all of the items are pertinent to any one supply, and in some cases items not in the list would be important additions to the survey list. Reference should be made to parts II and III of this manual for certain detailed recommendations bearing on various parts of this outline.

A. GROUND WATER SUPPLIES

1. Character of local geology; size and topography of catchment area; slope of ground surface.

2. Nature of soil and underlying porous strata—whether clay, sand, gravel, rock (especially porous limestone); coarseness of sand or gravel; thickness of water-bearing stratum; depth to water table; location and log of wells in vicinity in use and/or abandoned.

3. Slope of water table, preferably as determined from observational wells, or as indicated presumptively but not certainly, by slope of ground surface.

4. Extent of drainage area likely to contribute water to the supply; population on the drainage area.

5. Nature, distance, and direction of local sources of pollution.

6. Possibility of surface-drainage water entering the supply, and of wells becoming flooded; methods of protection.

7. Methods used for protecting the supply against pollution, by means of sewage treatment, waste disposal, and the like.

8. Well construction: Material, diameter, depth of casing; depth to strainers or perforations; length of strainers or perforations.

9. Protection of collecting well at top and on sides; protection other than check valve, or gate valve, against backflow of drain; protection of collector lines, etc.

10. Pumphouse construction (floors, drains, etc.); capacity of pumps; drawdown when pumps are in operation.

11. Availability of an impure supply, usable in place of normal supply, hence involving danger to the public health.

12. Disinfection; equipment; supervision; laboratory control.

Examples of Sanitary Defects in Ground Water Supplies:

1. Caves, sink holes, or abandoned borings, used for surface drainage, or sewage disposal, in vicinity of the source; fissures or open faults in strata overlying water-bearing formations.

2. Casing of tubular wells leaky, or not extended to sufficient depth, or not extended above ground or floor of pump room, or not closed at top; or casing improperly used as a suction pipe.

3. Collecting well, or reservoir, subject to contamination by backflow of polluted water through improper drain or by entry of surface drainage. Lack of covers, improperly designed manholes, vent openings, etc., which may permit contamination.

4. Source of supply or structures subject to flooding.

5. Use of tile pipes, or other conduits, that are not tight where the ground water may be contaminated.

6. Leak in systems under vacuum.

7. Air-lift line, or lines, cross-connected to a sewer or secondary water supply.

8. Wells located near sewers; pit privies; cesspools; septic tanks; subsurface tile systems; drains; barnyards; pits below ground surface; or other sources of contamination.

9. Wellheads, well casings, pumps, pumping machinery, exposed suction pipes, or valve boxes connected with suction pipes, located in pits extending below the ground surface.

10. Manufacturing and industrial plant wastes discharged on watersheds, or into underground strata causing contamination of ground-water supplies.

B. SURFACE-WATER SUPPLIES, UNFILTERED

1. Nature of surface geology; character of soils and rocks.

2. Character of vegetation; forests; cultivated and irrigated land, including salinity, effect of irrigation water, etc.

3. Population and sewered population per square mile of catchment area.

4. Methods of sewage disposal, whether by diversion from watershed or by treatment.

5. Character and efficiency of sewage-treatment works on watershed.

6. Proximity of sources of fecal pollution to intake of water supply.

7. Proximity, sources and character of industrial wastes, oilfield brines, acid mine waters, etc.

8. Adequacy of supply as to quantity.

9. For lake or reservoir supplies: Wind-direction and velocity data; drift of pollution; sunshine data (algae).

10. Character and quality of raw water: Coliform organisms (M.P.N.); algae; turbidity; color; objectionable mineral constituents.

11. Nominal period of detention in reservoir, or storage basin.

12. Probable minimum time required for water to flow from sources of pollution to reservoir, and through reservoir to intake.

13. Shape of reservoir, with reference to possible currents of water, induced by wind or reservoir discharge, from inlet to water-supply intake.

14. Measures taken to prevent fishing; boating; landing of airplanes; swimming; wading; ice cutting; permitting animals on marginal shore areas, and in or upon the water, etc.

15. Efficiency and constancy of policing.

16. Disinfection of water: Kind and adequacy of equipment; duplication of parts; effectiveness of treatment; adequacy of supervision and laboratory control; contact period after disinfection; whether residual free chlorine or chloramines used in chlorinated water; residuals carried.

17. Pumping facilities—Pumphouse; pump capacity and standby units; storage facilities.

Examples of Sanitary Defects:

1. Absence, or inadequacy, of chlorination, or lack of proper control of chlorination; insufficient contact period when chloramines only are present in treated water.

2. No restrictions on recreational use of streams and reservoirs, together with their marginal lands, in the local catchment area.

3. Existence of sources of pollution, such as population on watershed, lumbering, hunting, grazing, and other activities; leaching cesspools, or sewers draining into streams or lakes of the catchment area, or into the marginal lands adjacent to them.

4. Improper location of intake with respect to bottom of reservoir and current, or to surface-drainage-water inlets.

5. Intake exposed and accessible to trespassers.

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6. For lake supplies: Vessels passing near intakes; drift of ice fields; dumping of dredgings, garbage, etc., into lake near intakes; inadequate toilet facilities on cribs.

C. SURFACE WATER SUPPLIES, FILTERED

1. Catchment area: Size, topography; population density, sewered and unsewered; surface geology; reservoirs, their capacity and location.

2. Sources of pollution: Nature; distance from intake, including miles and rate of flow; amounts and distances of sewered population.

3. Sewage treatment on watershed: Extent; methods; population served; effectiveness and uniformity of results.

4. Raw-water characteristics: Turbidity, color, alkalinity, hardness, iron, etc.; bacterial quality, average and ranges; variations in quality, especially after heavy rainfall or at times of high run-off.

5. Capacity of filter plant (M.G.D.): Rated output, average and maximum daily; maximum capacity of raw-water pumps; standby equipment.

6. Coagulant system: Type, as solution or dry feeding; chemicals used; dosage rates, average, maximum, and minimum; number and capacity of units; reserve units.

7. Mixing and flocculation basins: Type, flash mixing, average and minimum times; flocculation, average and minimum times; number, size and arrangement of units; provisions for cleaning.

8. Sedimentation basins, number, size and retention capacity; plain sedimentation; postcoagulation sedimentation; methods of cleaning; flexibility of operation; efficiency of turbidity and bacterial removal.

9. Filters: Pressure or gravity type; number; sizes and rated capacity, net filtering area; effective size and uniformity coefficient of sand; washing system, direct or from storage, rates of wash-water application; loss-of-head gages; rate controllers, average and maximum rates of filtration.

10. Filtered-water storage: Capacity; location; arrangement: covered or uncovered; protection against contamination; methods of cleaning; added storage in distribution system.

11. Aeration: Purpose; kind; capacity; location in purification system; efficiency.

12. Disinfection: Kind; stages, if more than one; location in purification system; capacity; method of operation; operation control; average, maximum and minimum dosage; chlorine—ammonia

ratios, if ammonia is used; simple or "break-point" chlorination, if used; efficiency of each stage; period of chlorine or chloramine contact before delivery.

13. Plant operation and control: Technical supervision, trained or untrained, full-time or part-time; number of operators; laboratory control, kind and frequency of tests; plant and laboratory records, kind, extent, use, etc.; meteorological records.

Examples of Sanitary Defects:

1. Excessive raw-water pollution in relation to extent of treatment provided (see sec. II, A, 1., p. —); existence of nearby uncontrolled sources of raw water pollution.
2. Bypass connections for raw water, or partially treated water, whereby such waters may be discharged into the distribution system.
3. Existence of cross-connections, bypasses, or concrete channel walls within the plant, such as between conduits or basins carrying untreated or partly treated water, and those containing completely treated water.
4. Lack of reserve capacity of treatment works, necessitating excessive overloading, or occasional bypassing of units.
5. Lack of competent supervision and operation, or of adequate (part II, C, 2., p. —) laboratory control.
6. Deficient or inaccurate operation or laboratory records. (part II, C, p. —).
7. Lack of suitable devices for measuring and recording volumes of water treated; for maintaining continuity of coagulant and chlorine dosage; deficient retention periods in settling basins (part II, B, 4., p. —); or areas, depths, sizes of sand and washing facilities for filters.
8. Lack of or deficiency in proper chlorination equipment and control, or failure to maintain proper chlorine residuals in the treated effluent at all times.
9. Lack of suitable protection for purified water; storage capacity less than requirements for safety.
10. Improper location of water-treatment plant or inadequate protection with respect to flood waters.

D. PUMPING STATION AND COLLECTING SYSTEM

1. Location and protection with reference to flooding.
2. Number, type and capacity of pumps, including reserve; condition of equipment and method of operation; condition of suction pipes.

3. Location of suction pipes relative to sources of pollution.

4. Emergency intakes.

5. Emergency supply of power; record of power shut-down; effect of shut-down on surges through conduits, etc.

6. Recording apparatus on suction-well elevation; rise and fall of suction-well elevation.

7. Screens for fish and debris.

8. All sewers cast iron, or otherwise.

9. Curb walls around suction wells to protect against surface drainage.

10. Continuous or intermittent operation.

Examples of Sanitary Defects:

1. Leaky suction pipes.
2. Pump not self priming; unsafe water used for priming.
3. Suction well subject to pollution through backflow of polluted water through drain.
4. Suction well or suction pipes unprotected from surface or subsurface pollution.
5. Improper location or inadequate protection with reference to flood waters.
6. Lack of suitable provision for ensuring continuity of pumping service under all possible conditions.

E. DISTRIBUTION SYSTEM (EXCLUSIVE OF RESERVOIRS OR STANDPIPES)

1. Area and population supplied, proportion to total within corporate limits.
2. Adequacy of distribution system with respect to area served; sizes of mains and laterals, circulation of water; storage provided.
3. Type of distribution system: Whether gravity, direct pumping, indirect pumping, including capacity of pumps, etc.
4. For above water crossings: Flexibility of pipe joints for maintaining tightness under forces due to vibration and temperature changes including freezing; protection of pipe from impact of run-away vehicles, flood waters, and objects carried by flood waters.
5. For underwater crossings: Use of flexible watertight joints; provision of valves located above flood level at each end of crossing; duplicate lines; equipment installed for making pressure tests to detect leakage; sampling taps at each end of crossing; provision

for blowing off such sections of pipe to waste above ground level; distance pipe is laid below bottom of stream bed.

6. Use of common, or separate, trenches for laying water mains and sewers; practice concerning crossings of water and sewer lines.

7. Disinfection procedure followed in laying new mains, or repairing existing mains.

8. Method of draining hydrants: Sewers, dry wells, ground surface, other.

9. Elevation of booster-station floor level with regard to ground level; location of booster-pump suction lines relative to sources of pollution; possibility of developing negative heads in booster-pump instaliations drawing directly from the distribution system.

10. Method of delivery of water from public supply to some other water system which uses unsafe water.

11. Adequacy of piping system for maintenance of positive pressure in all parts of the distribution system, under normal usage, at all times.

Examples of Sanitary Defects:

1. Existence of cross-connections between primary supply and secondary supply of questionable safety at any point in the distribution system.

2. Return to the system of any water used for cooling; hydraulic operations, etc. (This is not intended to rule out the use of the barometric-type condenser, or an entirely closed cooling circuit, at the water-supply plant.)

3. Absence of, or inadequate, protection; lack of covers; improper location of distribution reservoirs, standpipes, or elevated pressure tanks.

4. Intermittent service, resulting in reduced or negative pressures in distribution system; sizes of mains and laterals inadequate for preventing negative pressures; presence of dead ends permitting reduced or negative pressures.

5. Connections to sprinkler systems using toxic solutions as antifreeze.

6. Repumping on consumer premises when pressure is low, causing negative head.

7. Connection to sewers and sewer-flushing chambers, and improperly located blowoffs in distribution system.

8. Existence of hydrant drain lines connected to sewer.

9. Presence of a secondary nonpotable water system on premises where a public system exists, unless adequate regulations and enforcement are provided to prevent the occurrence of cross-connections.

10. Lack of, or inadequate, enforcement of plumbing regulations and/or ordinances designed to protect the water supply against the possibility of backflow from plumbing fixtures or from mechanical equipment supplied with water from the public water supply.

11. Connection of new pipe lines to the system without prior disinfection of pipes.

12. Existence of tile, or other leaky pipes, in distribution system.

13. Improper location of water pipes in relation to sewers and storm-water drains.

F. STORAGE (RESERVOIRS ON DISTRIBUTION SYSTEM)

1. Use, location, and capacity of reservoirs and standpipes.

2. Reservoir sites, protection from trespassers; location with respect to sources of pollution; character of local geology.

3. Hazard of entry of flood and drainage waters; elevation of top of storage units with respect to highest known water level of any lake, pond or stream the waters of which might approach storage units; precautions taken to divert surface drainage from the storage units; water tightness of reservoir or storage unit.

4. Point of discharge, as sewers, ground surface, etc., of overflows, blow-offs, clean-outs, and drains from roof or bottom of water-storage units.

5. Elevation above ground level of walls of surface storage units.

6. Protection of valve pits for storage units against flooding and surface drainage, and point of discharge of drains therefrom.

7. Type of cover or roof, manholes, vents, overflows, control gages, and character of pipe connections to reservoir with regard to danger of leakage at points of entry.

8. Disinfection practice for new reservoirs or after cleaning and repairs on existing units.

Examples of Sanitary Defects:

1. Presence of earth formations at the reservoir site such as limestone, broken lava rock, coarse gravel, etc., whose interstices are in the form of channels, joints, or fissures and hence provide too little filtering action to prevent contamination from reaching the reservoir; poor surface-drainage conditions; insufficient dis-

tance from bodies of surface water or sources of contamination; top of reservoir not above ground or above level of flood waters.

2. Unsatisfactory materials, poor state of repair, cracks, lack of proper cover; vents and overflows that do not exclude birds, dust, rain, insects, etc.

3. Water-level indicators and control gages that permit entrance of contamination into stored water.

4. Curbing or roof coping interfering with roof drainage.

5. Manholes and covers of flush type, and covers or manholes which permit leakage of drainage into the reservoir or storage unit.

6. Drains from reservoirs to sewers or surface waters when backflow therefrom can reach reservoir.

7. Valve stems projecting through reservoir covers not protected.

PART II

RECOMMENDED SANITARY REQUIREMENTS FOR WATER TREATMENT SYSTEMS

A. GENERAL REQUIREMENTS

1. Extent of Treatment

For purposes of classification with respect to treatment requirements, waters acceptable for treatment may be divided into four groups. For practical purposes coliform bacterial content of the raw water can be expressed either in terms of "most probable numbers" or "Phelps Index", without changing the limiting coliform averages indicated for the various water groups. (See Public Health Reports Reprint No. 1170 *(2)*, July 15, 1927, pp. 7–11 and 18–19).

Group I. Water Requiring No Treatment. This group is limited to underground waters not subject to any possibility of contamination, and meeting, in all respects, the requirements of the Public Health Service Drinking Water Standards, as shown by satisfactory, regular, and frequent sanitary inspections and laboratory tests.

Group II. Waters Requiring Simple Chlorination, or Its Equivalent. This group includes both underground and surface waters subject to a low degree of contamination, and meeting the requirements of the Public Health Service Drinking Water Standards *(1)* in all respects except as to coliform bacterial content, which should average not more than 50 per 100 ml. in any month.

Group III. Waters Requiring Complete Rapid-Sand Filtration Treatment, or Its Equivalent, Together With Continuous Postchlorination. This group includes all waters requiring filtration treatment for turbidity and color removal; waters of high or variable chlorine demand; and waters polluted by sewage to such an extent as to be inadmissible to groups I and II, but containing numbers of coliform bacteria averaging not more than 5,000 per 100 ml. in any one month and exceeding this number in not more than 20 percent of the samples examined in any one month.

Group IV. Waters Requiring Auxiliary Treatment in Addition to Complete Filtration Treatment and Postchlorination. This group includes waters meeting the requirements of group III with respect to the limiting monthly average coliform numbers, but showing numbers of coliform bacteria exceeding 5,000 per 100 ml. in more than 20 percent of the samples examined during any one month and not exceeding 20,000 per 100 ml. in more than 5 percent of the samples examined during any one month.

Note. "Auxiliary treatment" as used here is presedimentation or prechlorination, or their equivalents, either separately or combined, as may be necessary. Long-time storage, for periods of 30 days or more, represents a permanent and reliable safeguard which in many cases would provide something more than an effective substitute for one or both of the two other methods indicated.

Remarks. *(a)* Although group I conceivably might include exceptional surface waters free of any possible contamination and further protected by storage, it hardly may be considered as a safe general rule to admit any surface water to a public supply without chlorination as a minimum safeguarding treatment, in view of the present increased hazards of chance contamination resulting from the extension of recreational and migratory travel to many hitherto inaccessible places.

(b) The limiting monthly average coliform numbers stated for waters of groups II and III are intended as guides rather than inflexible rules, though they are based on extensive observational data *(2)* fairly representing present water-treatment practice in this country. Consideration should be given to all aspects of the character and quality of the raw water; its range and suddenness of fluctuation in concentration of constituents which would influence the efficiency of the water-treatment process; the size and complexity of the water-treatment plant, and the type of supervision provided, in addition to the bacteriological characteristics of the raw water. Certain recent improvements in water chlorination and its control offer promise of increasing the margin of safety

of water-purification efficiency, with respect to bacterial removal. These improvements have not become fully incorporated into general practice throughout the country, and they should not be regarded as warranting any relaxation in the requirements for raw-water quality which experience and present standards of safety indicate as being necessary for providing adequate protection to sources of water supply in general.

(c) For waters of group IV, which differ from those of group III only in respect to variability, auxiliary treatment is intended mainly as a factor of safety in controlling variations in coliform numbers within the range of 5,000 to 20,000 bacteria per 100 ml. The larger of these two figures represents the maximum safe limit for prechlorination, or its equivalent, in addition to filtration treatment and postchlorination.

(d) Waters failing to meet the requirements of groups I, II, III, or IV are considered as unsuitable for use as a source of water supply, unless they can be brought into conformance with these requirements by means of prolonged preliminary storage, or some other measure of equal permanence and reliability.

2. Other Raw Water Requirements

Waters acceptable for treatment, in addition to meeting the aforesaid bacterial requirements, should not contain any toxic, taste-producing, or otherwise harmful substances, or organisms, not readily and completely removable by ordinary water treatment. Raw waters should be free of excessive amounts of acid, microscopic organisms, and organic matters causing any interference with the normal operation and efficiency of water-treatment processes.

B. DESIGN AND CONSTRUCTION

In general, the design and construction of individual water-treatment plants will vary with local circumstances and should be in accord with the results of experiments on the water to be treated. The following recommendations are intended only as a general guide to good practice and are to be interpreted somewhat broadly in the light of the particular raw-water characteristics and other conditions which may be involved in a given situation.

1. Plant Delivery Capacity

The delivery capacity of a treatment plant, including filtered-water storage at the plant, should always be in excess of the

maximum expected draft on any day of the year. The ratio of maximum day draft to the average day draft varies considerably with the nature of the particular community, hence an evaluation of the adequacy of the delivery capacity of a treatment plant should be based on a study of the maximum expected draft on any day of the year, having regard to past experience and making allowance for future conditions and growth of the community. The plant should be able to meet the maximum daily draft to be expected some years in the future. Plant expansion is indicated when the maximum expected draft, 4 or 5 years in the future, approximates the present delivery capacity of the treatment plant.

2. Plant Location

The plant should be located so that no conduit, basin, or other structure containing or conducting water in the process of treatment can possibly be affected by leakage from any sewer, drain or other source of contamination. If located in a valley, the site should be adequately drained so that no surface water can gain access to wells, basins, filter tanks or other units.

The water-treatment plant preferably should have greater protection than, and at least as much protection, against floods, as the community it serves. This protection against floods may be provided by locating the plant on high ground above flood levels, by construction of levees, by installation of vertical centrifugal pumps with motors situated above high water level, etc. The adequacy of flood protection should be judged with regard to the flood heights to be expected, the structural soundness of the protective works, and the availability of sufficient auxiliary power and pumping equipment to assure the continual operation of pumps for the removal of flood waters under emergency conditions.

3. Presettling Reservoirs

The term "presettling reservoirs," as used here, denotes reservoirs used for the removal of turbidity by plain sedimentation, supplemented in special cases by the addition of coagulants and or chlorine. The term does not include the relatively small, so-called "grit reservoirs," commonly used in the Mississippi Valley for the removal of coarse silt and sand, rather than for the deposition of the finer clay particles.

Presettling reservoirs, if used, should be located above the influence of flood waters. They should be at least two in number, so as to permit continuous operation under all circumstances, and should be of sufficient capacity to afford a nominal retention period

of at least 1 day and preferably 2 or 3 days. Provision should be made for rapid and convenient removal of sludge from the reservoirs. In the treatment of highly polluted waters of variable quality, provision should be made for coagulation at the inlet and for prechlorination at the inlet or the outlet of the reservoirs, whenever such measures may be necessary. Reservoirs should be provided with boats and life preservers for the protection of employees.

4. Coagulation Sedimentation Basins

In order to insure continuous operation, basins for flocculation and sedimentation of coagulated waters should be at least two in number. The basins should be designed for operation in series or in parallel and preferably should provide a total retention period of at least 5 to 6 hours, except in the case of preliminary mixing and flocculating devices and continuous sludge removal, permitting somewhat lower periods with unimpaired efficiency.

With the well-designed basins of the conventional type, handling a well-coagulated water, a 2- to 4-hour theoretical retention period may be sufficient for preparation of the water for filtering. Inlets and outlets of ordinary straight-flow basins should be provided with baffles to "kill" the velocity at the inlet and be so located as to prevent short-circuiting. The maximum velocity of flow in the settling compartment should not exceed that which usually is provided in well-designed basins of this type. The length of settling compartments in such basins, if rectangular, preferably should be at least twice the width. Stilling compartments should be provided at basin inlets. If stream use will permit, sludge drains may discharge at points located well downstream from the intakes, at points removed from the influence of cross-currents passing the intake. Otherwise, suitable sludge-disposal areas should be provided. The depth of basins should be such as to maintain proper velocity of flow and sludge removal, the permissible depth being slightly lower with continuous sludge removal. Flow-line elevations should not vary more than a few inches above or below the normal level.

Coagulation and sedimentation plants of the sludge blanket type have been used successfully with various types of raw waters in a number of plants built in recent years. When the chemical and physical reactions in plants of this kind produce a floc with good settling properties, retention periods of an hour or less are sometimes permissible. Evaluation of plants of this type should be based on performance and operating results for existing installa-

tions; for proposed installations, experience with waters of similar character in other plants of this type should be reviewed.

Preliminary flash-mixing and flocculating equipment capable of adequate flexibility of adjustment to provide optimum flocculation under varying raw-water conditions is a desirable feature of well-designed, modern filtration plants and should be credited as a distinct addition to the sanitary protection afforded by a purification system. An ideal combination of flash mixing and flocculation would provide about 1 to 2 minutes of violent agitation followed by about 20 to 30 minutes of slow mixing to promote flocculation.

5. Coagulant System

Rapid-sand filtration plants should be provided with efficient modern devices for measuring and adding coagulants to the water under treatment. All chemical dosing equipment, whether of the dry-feed or solution-feed type, should have at least one unit in reserve throughout and should be provided with effective recording and alarm devices to ensure continuity of service at all times. An accurate flow meter should be provided for the water treated. Suitable gravimetric devices for measuring the amount of chemicals added from hour to hour should be provided for dry-feed equipment. Provision should also be made for checking the quantity of chemicals added by solution feed equipment. Recording devices may be installed on feeding weirs or on batch supply tanks, or the solution supply tanks may be installed on scales to permit gravimetric determination of feed rates. All chemical feed equipment should be capable of ready adjustment to variations in the flow of water being treated.

6. Filters—Slow-Sand

Slow-sand filters, if properly designed and operated, are applicable to the treatment of certain types of relatively clear waters. Preferably they should be covered; provided with loss-of-head gages; have a sand depth of 36 to 40 inches; and never be operated with less than 20 inches of depth. The sand should have an effective size of preferably 0.25 to 0.35 millimeters and the filters should be operated at rates of about 2.5 million gallons per acre daily. In operating slow-sand filters, care should be taken to avoid any sudden increases in the rate of filtration. The filter area should be provided in several independent units so that the quantity of water required at times of maximum draft can be supplied when some units are out of service for cleaning or repair work.

Preliminary treatment of water applied to slow-sand filters is sometimes provided. Such treatment may consist of simple sedimentation; sedimentation preceded by coagulation; or preliminary rapid filtration with or without coagulation and sedimentation. In these cases the objective is to condition the raw water, particularly with respect to the removal of turbidity, for more efficient or satisfactory treatment in the slow-sand filters. Depending upon the degree of preliminary treatment provided, the filtration rates for slow-sand filters may be appreciably increased. Under these circumstances, the conventional daily rate of 2.5 million gallons per acre may be doubled or even tripled.

7. Filters—Rapid-Sand

Rapid-sand filters should be preferably of the open gravity type, in order to permit ready and continuous inspection. Pressure filters are not recommended for the filtration of polluted waters; however, they do have a proper use in zeolite softeners. The depth, effective size, and uniformity coefficient of the sand should be in accordance with the requirements of adequate yield and filter efficiency. Sand depths of about 30 inches are recommended, with an effective sand size ranging from 0.40 to 0.50 millimeters and a uniformity coefficient from 1.5 to 2.0. However, sands of other characteristics than these may be used successfully, depending on local conditions, plant design, and characteristics of the water. The rate of filtration should conform to established practice, preferably not exceeding 2 gallons per minute per square foot of filtering area.

In general, rapid-sand filters should be designed and operated with a view to maintaining reasonably high efficiency of bacterial removal, and keeping the filtering medium in good condition, free of mud balls, cracks and other hindrances to efficient filtration. Present design practice indicates that backwash facilities should be available to provide an adequate quantity of water at a rate sufficient to provide a 50-percent increase or expansion of the sand depth. Suitable surface-wash equipment is useful in maintaining filter efficiency where there is a tendency to formation of mud balls. Efficient loss-of-head gages, rate controllers and other essential control devices should be provided. The filter area should be provided in several independent units so that the quantity of water required at times of maximum draft can be supplied when some units are out of service for cleaning or repair work.

8. Filtered-Water Storage Reservoirs

Filtered-water reservoirs at the plant preferably should be covered and located near to, but physically separated from, the

plant. However, where such reservoirs are located below filters, adequate protection against leakage of drainage water from other parts of the plant into the reservoirs should be provided. Trap doors and inspection openings should be properly sealed and locked. Suitable vents, protected against outside contamination, should be provided. All effluent pipes should be properly sealed against leakage and tested by frequent inspections. Filtered-water reservoirs should be thoroughly tight against external leakage; if practicable, be situated above the ground water table; and preferably should have no single walls in common with any other plant units containing water in a prior stage of treatment.

9. Cross-Connections, Open Connections and Partition Walls (See Part III-D)

a. No cross-connection should be permitted to exist in a filtration plant between any conduit carrying filtered or postchlorinated water, and another conduit carrying raw water, or water in any prior stage of treatment.

b. No conduit or basin containing finished water should be permitted to have a common division wall with another conduit or basin containing raw water or water in any prior stage of treatment.

c. Rewash or filter-to-waste conduits should not be directly connected to any drainage conduit, but should be protected by a suitable one-way, air-gap-delivery connection, to ensure that no backflow can occur under any condition.

d. No conduit carrying raw water, nor any water in a prior stage of treatment, should be located directly above another conduit carrying finished water, with a single, common partition between them. This rule is not strictly applicable where the water in a prior stage of treatment is conveyed in a cast iron, or other equally durable and impervious, pipe with tight joints, and is located where it is readily accessible for inspection and repair.

10. Drains

All drainage conduits should be constructed so as to be thoroughly tight against external leakage. They should discharge at points in a river or lake so located that no currents of water can, under any circumstances, be carried from a drain outlet to the plant intake, or to any other water intake located in the vicinity of the plant. No domestic, or other, sewer should be permitted to be discharged into a river or lake in the vicinity of a treatment-plant intake, or directly above such intake; nor should any drain

carrying contaminated surface water be permitted to be discharged likewise.

11. Chlorination

a. General. Chlorination equipment should be so selected, installed, and operated that continuous and effective disinfection is secured under required local conditions.

b. Chlorination Equipment. (1) All chlorination equipment should be installed so as to provide sufficient stand-by units for insuring uninterrupted operation. The capacity of chlorination equipment should exceed the highest expected dosage to be applied so as not to require use of stand-by equipment for normal operation. The determination of the highest expected dosage should be made under the approval of the supervising agency, as the Public Health Service, the State department of health, etc., with due regard to the characteristics of the water to be treated and the treatment involved (3), e. g., break point, free chlorine, chloramine, etc. Stand-by units should be operated frequently to insure workability. A complete stock of spare parts and tools should be maintained for emergency replacements or repairs. Chlorination equipment should be capable of satisfactory operation under every prevailing hydraulic condition at the plant.

(2) Automatic proportioning of the chlorine dosage to the rate of flow of the water treated should be provided at the larger plants and, in general, at all plants where the rate of flow varies more than 50 percent above or below the average flow. In the latter case and where the water being chlorinated is pumped by manually controlled pumps, manual adjustment of the chlorine dosage is permissible, provided the certainty of making necessary changes in the chlorine dosage with changes in the pumping rates is assured. Manual control of the chlorine dosage is generally permissible where the rate of flow is relatively constant and an attendant is always on hand to effect promptly the necessary adjustments in dosage. Automatic proportioning of the chlorine dosage to the chlorine demand of the water is also desirable, particularly where the quality of the water is subject to change without warning.

(3) A reliable and uninterrupted supply of water, free of coarse suspended matter, should be available under adequate pressure to ensure the continuous operation of solution-feed chlorinators. Hydraulically- or electrically-driven pumping equipment, if used for maintaining such pressure, should be provided with alterna-

tive sources of power, where necessary, to ensure continuous operation.

(4) Scales, preferably of the indicating and recording type, should be provided for weighing the cylinders of chlorine and checking the losses in weight of chlorine as fed from the cylinders during successive intervals of time. These scales should be sufficiently accurate and sensitive to measure such losses with suitable precision.

(5) A sufficient number of cylinders of chlorine should be connected to the chlorinator in use so that adequate operating pressures are maintained at various temperatures, and a sufficient reserve supply of chlorine should be on hand at all times to assure continuous chlorination of the water.

c. Hypochlorite Solutions. (1) Solutions of calcium or sodium hypochlorite should be prepared in a separate mixing tank, then diluted and allowed to settle, so that only a clear supernatant liquid is withdrawn to the solution storage tank and to the chlorinator.

(2) The strength of stored calcium-hypochlorite solutions should be checked frequently by laboratory test in order to ensure that no loss of strength has occurred. Fresh calcium-hypochlorite solutions should be prepared every 4 or 5 days, unless properly alkalinized with sodium carbonate.

d. Safety Requirements. (1) Suitable gas masks and a small bottle of ammonia to test for leaks should be kept at convenient points immediately outside the room or enclosures in which chlorine is being stored or is in use. Gas masks should be inspected at regular intervals and kept in serviceable condition.

(2) Chlorinating equipment and cylinders of chlorine preferably should be housed in separate buildings above the ground level, as a measure of safety.

(3) The room, or building, housing chlorinators in service, should be maintained at a temperature above 60° F., but never in excess of the normal summer temperature of the atmosphere. The cylinders of chlorine should be shielded, where necessary, from excessive heat or cold. Neither direct heat nor hot water should be applied to cylinders of chlorine, nor to the cylinder valves.

(4) Adequate ventilation should be provided for all enclosures in which chlorine is being fed or stored.

(5) All joints of tubing connecting chlorine cylinders and chlorinators should be kept absolutely tight, and should be inspected frequently to ensure tightness. Tubing should slope upward from the cylinders.

e. Control of Chlorination. (1) Chlorine should be applied continuously to the filtered effluent at a point where thorough and rapid mixing with the treated water is effected. Free active chlorine should be in contact with the treated water for not less than 20 minutes; or chloramine preferably for at least 3 hours, before the treated water reaches the first consumer.

(2) The proper dosage of chlorine will be determined by regular and frequent routine bacteriological and residual-chlorine tests, both at the plant and at various points in the distribution system. In general, a safe and desirable minimum of residual free chlorine at distant points in the distribution system is 0.05 or 0.10 p.p.m., depending on the pH and temperature of the water (cf. tables I and II). For chloramines, the desirable residual is 1.0 to 2.0 p.p.m. The residual chlorine carried in the finished water as delivered from the treatment plant should be regulated accordingly. At times of threatened, or prevalent, outbreaks of water-borne disease, the residual chlorine should be maintained preferably at a minimum of 0.1 p.p.m. for free chlorine and 2.0 p.p.m. for chloramine, in all parts of the distribution system, regardless of tastes or odors in the delivered water. Similar measures should be taken in the event of any lapse in the normal efficiency of the treatment plant.

(3) Routine sampling points should be maintained at the treatment plant and at several vital points in the water-distribution system. Sample collections should be made regularly at the latter points and tested for bacteria and for residual chlorine. Chlorine-demand tests should be made occasionally on samples collected in the distribution system, for comparison with the results of similar tests at the treatment plant. Any abnormal increase in the chlorine demand, or decrease in the residual chlorine, at any point in the distribution system should be checked and, if consistently observed, followed up by a thorough physical investigation of that portion of the system.

(4) The tests for residual chlorine should be made in accordance with the current edition of the Standard Methods for the Examination of Water and Sewage *(4)*, published jointly by the American Public Health Association and the American Water Works Association. A distinction should be made between residuals existing as free chlorine and as chloramines. Several methods for this differentiation are available *(5, 6, 7, 8)*. Such tests should be made at least once during each successive period of 8 hours every day in the finished water at the treatment plant and at least three times weekly at regular sampling points in the distribution system.

(5) Special care should be taken to maintain a detailed and accurate record of chlorination and the results thereof. Such a record should show:

(a) Rate of flow of water treated.

(b) Gross weight of chlorine cylinder in use.

(c) Weight of chlorine used for 24 hours.

(d) Setting of chlorinator.

(e) Time of making and results of residual chlorine test.

(6) As a guide to plant operators, it is recommended that unless bacteriological and other tests indicate the need of maintaining higher minimum concentrations of residual chlorine, at least 0.2 p.p.m. of free chlorine should be maintained in the treated water after a contact period of at least 20 minutes in the distribution system beyond the point of chlorine application. When chloramine treatment is used for disinfection, the residual-chlorine concentration as indicated by the orthotolidine reagent should be similarly at least 2.0 p.p.m. after 3 hours of contact, and 1.0 to 2.0 p.p.m. at all points in the distribution system. Where "break-point" chlorination is practiced, a sufficient concentration of residual free chlorine should be maintained at the treatment plant so that it will be not less than 0.05 to 0.10 p.p.m. at all points in the distribution system. When required in specific instances, the minimum concentration of residual chlorine and the minimum retention period for the chlorinated water should be increased as directed by the State department of health.

(7) Recent studies conducted by the Public Health Service *(9, 10, 11) indicate that:*

(a) For a given contact period, and depending upon the pH and the temperature of the water being treated, the ratio of chloramine to chlorine necessary to obtain a 100-percent kill of *Escherichia coli* is approximately 25: 1 and will vary from 10: 1 to 60: 1.

(b) To obtain a 100-percent kill of *Esch. coli* at 2° to 5° C., it requires a contact period 1 to 10 times longer (average 3 times) than is required at 20° to 25° C. depending upon the pH of the water, when free chlorine is used at a given residual. When chloramine is used, a contact period 1 to 18 times longer (average 9) is required at the lower temperature.

(c) To obtain a 100-percent kill of *Esch. coli* at 2° to 5° C., it requires 1 to 7 times (average 4) as much free chlorine for the same period of contact as is required at 20° to 25° C., depending upon the pH of the water. When chloramine is used, 1 to 4 times

(average 2.5) as much residual chlorine is required at the lower temperature.

Tables I and II indicate the chlorine residual required to produce a 100-percent kill of *Esch. coli* for various pH values and for two temperature ranges at the contact periods stated. These data are presented for free chlorine and for chloramine.

TABLE I.—FREE CHLORINE. Lowest chlorine residuals producing a 100-percent kill of "Escherichia coli" for contact periods and temperatures indicated at various pH values

pH	2° to 5° C.			20° to 25° C.		
	10 minutes	20 minutes	60 minutes	10 minutes	20 minutes	60 minutes
7.0	0.03	0.03	0.03	0.04	0.04	0.04
8.5	.14	.07	.05	.07	.07	.05
9.8	.72	.40	.40	.30	.06	.06
10.7	>1.00	>1.00	.30	.40	.30	.03

TABLE II.—CHLORAMINE. Lowest chlorine residuals producing a 100-percent kill of "Escherichia coli" for contact periods and temperatures indicated at various pH values

pH	2° to 5° C.				pH	20° to 25° C.		
	40 minutes	60 minutes	90 minutes	120minutes		10 minutes	20 minutes	60 minutes
					6.5	1.50	0.90	0.30
7.0	1.80	1.50	1.20	0.90	7.0	1.80	1.20	.60
					7.8	>1.80	1.50	.90
8.5	1.80	1.80	1.80	1.80	8.5	>1.80	1.80	1.20
9.5	>1.80	>1.80	1.80	1.80	9.5	1.80	1.80	1.50
					10.5	>1.80	>1.80	1.80

It should be clearly understood that the data presented in table I for free chlorine are applicable only when the residual is present as free chlorine to the absolute exclusion of chlorine-addition products (chloramines, etc.). As indicated by the data in table II, the bacterial death rate with chlorine-addition products (chloramine) is markedly less than that with free chlorine.

The ratio of chlorine to nitrogen in the case of chloramines had no effect upon the bactericidal action of chloramine until this ratio approached 10 to 1. When the chlorine is present in such amounts, a certain quantity may be present as free chlorine

rather than as mono- or di-chloramine and this free chlorine, as already indicated, acts on the bacteria much more rapidly than the chloramines.

C. OPERATION CONTROL

1. Supervision

Every water-treatment plant engaged in purifying water for domestic use should be under the charge of a technically trained supervisor. For plants treating variable or highly polluted raw waters, there should be continuous full-time trained supervision. For certain types of small plants, part-time trained supervision may be practicable under favorable circumstances. Under these conditions, the supervisor should be in constant touch with the plant attendants and available on call in any emergency, and should visit the plant at least twice each week.

2. Laboratory Tests and Control

a. The schedule of laboratory tests followed in controlling the operation of a water-treatment plant will vary with the size of the plant and the character of the water treated, though certain minimum requirements may be stated. For the ordinary plant, the minimum schedule of laboratory tests should include determinations of air and water temperature, turbidity or color (or both), alkalinity, pH value, hardness, residual chlorine, bacterial count at 20° C. or 37° C. (or both), and coliform bacterial numbers, both presumptive and confirmed. Where "breakpoint" chlorination is practiced, a continuous record of free ammonia in the water to be chlorinated should be maintained. Occasionally special tests may be necessary, such as for residual alum, iron, manganese, taste and odor, or other undesirable constituents of the final effluent. Where prechlorination is used in addition to postchlorination, tests for residual chlorine should be made at each major stage of treatment and, in the raw water, tests for chlorine demand should also be made.

b. For operation control at the plant, the frequency of tests, particularly for turbidity, residual chlorine, bacterial count and coliform organisms, though dependent on the character of the water treated and on its variability, should be such that at least one test every 24 hours, on each day of the week, is carried out. For the larger plants, at least three sets of samples should be collected daily for bacteriological tests. Determinations of turbidity and residual chlorine should be made more frequently, sometimes at

hourly intervals when the character of the raw or partly treated water is changing rapidly.[1]

c. An important, though somewhat less tangible, element in judging the efficiency of plant operation is the general appearance of the plant and its surroundings. A neat well-kept plant with attractive grounds is almost invariably an index of efficient operation, although in some of the smaller plants, this criterion may not always be infallible. Mere neatness in the external maintenance of a plant, however, cannot offset lack of proper training on the part of the operator.

In rating the general efficiency of operation control, the following items are of primary importance:

(1) Training and experience of supervisor and operating staff.

(2) Adequacy of operation records.

(3) Efficiency of laboratory control.

(4) Suitability of plant design and construction to the character and pollution of the raw water.

(5) Capacity of the plant in relation to the average and maximum required output.

PART III

RECOMMENDED GENERAL SANITARY REQUIREMENTS FOR WATER-DISTRIBUTION SYSTEMS

A. GENERAL

1. A water-distribution system should be designed and constructed so as to provide, at all times, an adequate supply of water, at ample pressure, in all parts of the system.

2. The safety and palatability of the water should not be impaired in any manner while flowing through the distribution system, or any part thereof.

3. The system should be provided with sufficient valves and blow-offs so that necessary repairs can be made without undue interruption of service over any considerable area. Blow-off connections to sewers should be prohibited. In level terrain this may require provisions for dewatering of blow-off manholes with pumps.

4. No unprotected open reservoir, or physical cross-connection whereby unsafe water can enter the distribution system, should be permitted.

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[1] The following rule, wholly arbitrary, would give sampling frequencies depending in part on the daily volume of water treated and on the density of raw water pollution:

$$N = \sqrt[3]{VC}$$

N = number of samples per 24 hours
V = volume of water treated in million gallons daily
C = coliform number, M.P.N., in thousands per 100 ml.

According to this rule, the number of samples per 24 hours would range from 1 to 2 for a 1-m.g.d plant with a raw-water coliform number of 1 to 5 thousand per 100 ml., and from 5 to 8 for a 100-m.g.d plant with the same range in coliform numbers.

5. The system should be tight against excessive leakage and its various mains and branches should be separated from rivers and other possible sources of contamination.

6. The system should be designed so as to afford effective circulation of water, with a minimum of dead ends.

7. The distribution system should be maintained in a sanitary manner, with due precautions against contamination of the water in any part of it as the result of necessary repairs, replacements or extension of mains.

8. Frequent and regular bacteriological examinations should be made of water samples collected at various control points in the distribution system, with an immediate and thorough checking of any unusual results.

B. PIPING SYSTEM

1. The piping system should be designed to maintain an adequate positive pressure of water in all parts of the system, with due regard to unusual drafts on any part of the system. Water mains should be of adequate size, and pressure-equalizing standpipes or reservoirs should be located at suitably distant points from the pumping or main supply station.

2. Joints should be of such design and installation that leakage, evaluated on a pressure basis of 150 pounds per square inch, is less than 100 gallons per 24 hours, per mile of pipe, per inch of nominal diameter. Materials used for caulking should be of such a character as not to foster the growth of coliform bacteria and should be free from oil, tar, and/or greasy substances.

3. Corrective water treatment should be instituted where deposits in the mains tend to reduce the effective size and capacity of the pipes. For biological deposits, heavy chlorination may be effective.

4. Where dead ends are necessary as a stage in the growth of the system, they should be located and arranged with a view to connecting them ultimately so as to provide circulation.

5. Many crossings of water pipes and sewers cannot be prevented, except at an appreciably increased cost in the provision of these facilities. On the other hand, potential health hazards come about because of such crossings, particularly when the sewer is at a higher elevation than the water pipe. Leaks may occur in both water and sewer pipes because of improperly constructed joints, corrosive action of soils and water, settling of soils around these pipes, etc. Under the circumstances, sewage contamination may enter the water pipes, depending upon the pressure conditions

in them; the extent of sewage leakage; and the nature of soil formations. Accordingly, it is recommended that water pipes be laid, so far as possible, at an elevation above that of nearby sewers. Where this cannot be done because of topography or other controlling conditions, extra care should be taken to install pipe of durable and corrosion resistant material with tight, durable joints in both the water pipes and sewers. Similar precautions should be taken with respect to water-service lines.

6. When nonferrous metal pipe is to be used for water-service lines, consideration should be given to the corrosive effects of the particular water on the metal to be used, in view of the possible development of deleterious physiological effects upon consumers, resulting from solution of the metal.

7. Due sanitary precautions should be taken in laying new water pipes. Where avoidable, pipe should not be laid in water nor where it can be flooded with water or sewage in the laying process. Leakage tests should be made by means of hydrostatic pressure. New mains should be kept filled with a strong hypochlorite or chlorine solution (40–60 p.p.m. of chlorine) for at least 24 hours, and then drained before being placed in service. Fire hydrants should not be drained into the sewers or storm drains. Valve chambers should be of watertight construction and should not be connected directly to a storm or sanitary sewer.

C. STORAGE

1. There should be sufficient storage capacity in the system to assure, at all times, an adequate supply of water at ample pressure in all parts of the system. Consideration should be given to the storage or reserve requirements for emergency use, as for fire fighting, and in meeting the drain caused by a break in a large water main.

2. Preferably, storage reservoirs should be located above ground-water level and in such a location that surface water and underground drainage is away from the structures. Provisions should be included to guard against the sanitary hazards related to location factors such as ground-water levels, movements and quality, character of soil, possibility of sewage pollution, and overtopping by floods. Sites in ravines or low areas subject to periodic flooding should be avoided. Any sewer located within 50 feet of a storage reservoir should be constructed of extra heavy cast-iron pipe with tested watertight joints.

3. All storage reservoirs should be protected against flood waters or a high water level in any stream, lake, or other body

of water. If practicable, the reservoir should be placed above the high water level. The structure and appurtenances should be constructed so as to be watertight.

4. The ground surface about the reservoir should be sloped so as to drain or divert surface water away from the reservoir and should be so graded that no pooling of surface water will occur within the vicinity of the reservoir.

5. Any overflow, blow-off, or clean-out pipes from storage reservoirs should discharge freely into an open basin from a point not less than two diameters of the discharge pipe above the top or spill line of such receiving basin. If such drainage pipes are at any time likely to be submerged by surface or flood waters, they should be provided with double check valves to guard against backflow of contaminated water into the reservoir. If the receiving basin is so located as to overflow above the ground level it may be drained into a storm sewer; otherwise it should be drained by a reliable drainage pump. All overflow, blow-off, or clean-out pipes should be turned downward and screened with removable 24-mesh screen to prevent the entrance of rain, dust, birds, insects, rodents, and other contaminating materials.

6. All inlet and outlet pipes connecting to storage reservoirs should be properly supported and constructed so as to minimize settling, and the wall castings should be provided with suitable collars to ensure a watertight connection.

7. A suitable and substantial cover should be provided for any reservoir, elevated tank, or other structure used for water storage. Covers should be watertight, of permanent material, and constructed so as to provide drainage away from the cover and prevent entrance of contamination into the stored water. The surface of covers on storage reservoirs should not be used for any purpose in connection with which contaminating matter is likely to be produced.

8. Manholes and manhole covers, where necessary on covers over storage reservoirs, should be fitted with raised watertight walls projecting at least 6 inches above the level of the surrounding concrete surface. Each manhole frame should be closed with a solid watertight cover, preferably with edges projecting downward at least 2 inches around the outside of the frame. The manhole covers should be provided with a sturdy locking device and should be kept locked at all times except when actually in use.

9. Any necessary vents or openings through covers on storage reservoirs, for water-level control gages or other purposes, should be constructed so as to prevent the entrance of dust, rain, snow,

birds, insects, or any other materials which might include contamination.

10. Storage reservoirs should be operated at all times in such a manner as to maintain the highest sanitary quality of the water.

D. INTERCONNECTIONS, BACKFLOW CONNECTIONS, CROSS AND OPEN CONNECTIONS

Definitions

(1) Cross-connection—Any physical connection or arrangement of pipes between two otherwise separate water-supply systems, one of which contains potable water and the other water of unknown or questionable safety, whereby water may flow from one system to the other, the direction of flow depending upon the pressure differential between the two systems.

(2) Open connection—A piping arrangement which provides an air gap between two water-supply systems and which may become a cross-connection or interconnection by the insertion of a length of pipe into the air gap.

(3) Backflow connection—Any arrangement whereby the flow of water or other liquids into the distribution system of a potable supply of water can occur from any source or sources other than its intended source.

(4) Interconnection—A physical connection between two potable water-supply systems.

1. In general, no physical cross-connection should be permitted between a public or private water distribution system containing potable water, and any other system containing water of questionable quality or any other contaminating or polluting substance.

2. Open connections, physically separated, may be permissible under regulation and supervision by the local, or State health department.

3. House or industrial toilet or sink fixtures capable of backsiphonage into the water system should be classed as backflow connections and therefore be prohibited.

4. Interconnections may be permissible when approved by the State department of health.

PART IV

DISCUSSION OF CHEMICAL AND BACTERIOLOGICAL REQUIREMENTS FOR POTABLE WATER AS EXEMPLIFIED BY THE 1946 DRINKING WATER STANDARDS

A. CHEMICAL

It is fairly obvious that a water which is turbid, or colored to a degree which is easily noticeable, or which has an unpleasant or unusual odor or taste, will be looked upon with suspicion by the consumers to whom it is served for drinking purposes. For this reason its use should not be permitted where clarification of the water is practicable, or where a more acceptable supply is available.

The presence of considerable amounts of calcium and magnesium salts makes the water unsuitable for use in washing, and also unpleasant for drinking, to persons who have been accustomed to softer water. Persons who are accustomed to the harder waters may find the softer waters less agreeable to their taste. Although it is open to question whether it would be justifiable to require the dilution of highly mineralized water by distilled water in order to keep within the limits specified in the 1946 Drinking Water Standards, it would be proper to require common carriers to select the local supplies which most nearly fulfill the requirements of the Standards with respect to mineral content.

Insofar as the chemical composition of the water may cause inconvenience by its irritating effect upon the intestinal canal, or by any more serious effect upon well-being, the certifying authority will be justified in requiring that due regard be paid to this matter by common carriers. Unfortunately, it is difficult to secure reliable information concerning the physiological activity of salts as found in waters. Individual variations are important. It is universally admitted that poisonous or otherwise harmful elements or salts in significant quantities, such as lead, hexavalent chromium, arsenic, fluoride, or selenium, should not be allowed in water which is to be used for drinking or culinary purposes. It is difficult, however, to fix limits for the less poisonous substances or salts which are normally present. The effect of sulphates and especially of magnesium sulphate is well recognized, and it would be desirable to avoid the use of waters in which the concentration of these salts is so high as to be annoying. The use of salts of barium or of hexavalent chromium for treating the water, or water system, should not be allowed in a drinking-water

supply. Whereas molecularly dehydrated phosphates have come into use for water treatment but sufficient information on the physiological effects of small amounts of these salts is not available, their use in excess of 10.0 p.p.m. for treating any drinking water should be avoided. Where waters are treated with chemicals in order to soften or to purify them in any way, it is desirable that any excess of the chemical used should be avoided. Limits for alkalinity resulting from excess lime or other softening procedures are recommended in the Drinking Water Standards. More than a small amount of free chlorine (1.0 p.p.m.) of chloramine (2.0 p.p.m.) is objectionable in the effluent from a treatment plant, because of the resulting chlorinous taste in the water. In general, it is considered proper to insist that an effort should be made to find waters which are as satisfactory as possible from the standpoint of chemical characteristics, but with due regard to the region within which the water supply must be obtained. It should be realized that some chemical characteristics of water may be permitted from a public health standpoint which will cause difficulties in the water plant and distribution system. The impairment of the water system by such chemical characteristics is an economic problem which should be corrected to prevent economic losses and does not justify a public health regulation to induce corrective action.

Relation Between pH, Total Alkalinity, Hydroxide, Carbonate and Bicarbonate Alkalinities in Waters[2]

In the chemical analyses of water, it is often desirable to know the concentrations of hydroxide, carbonate and bicarbonate alkalinities present in the sample, as well as the total alkalinity to methyl orange. According to the Standard Methods for the Examination of Water and Sewage *(4)*, the OH^-, $CO^=_3$, and HCO^-_3 components of a total alkalinity are calculated from the values for the methyl orange *(T)* and phenolphthalein *(P)* alkalinities by means of the relations given in part II, section VI, paragraph 3.1 (p. 66, eighth edition). Experimentally, the phenolphthalein titration of samples containing carbon dioxide and mixed carbonates is far from satisfactory. Furthermore, the formulae for calculating the amount of OH^-, $CO^=_3$, and HCO^-_3 alkalinity from the values of P and T ignore the laws of chemical equilibrium. The formulae assume that neither OH^- and HCO^-_3 nor $CO^=_3$ and CO_2 may exist in the same solution, assumptions which

[2] This discussion is pertinent to the requirements of sec. 4.22, (1), (2), (3), of the Drinking Water Standards.

are quantitatively incorrect. Also, the formulae give values for CH^- which too often do not check with those calculated from the pH of the water.

On the basis of the ionization equilibria of carbonates and water, DeMartini *(12)* formulated equations by means of which the concentrations of CO_2, HCO^-_3, $CO^=_3$, and OH^- present in a given sample can be calculated from the values for pH and total alkalinity. Moore *(13)*, using the best available values for the ionization constants of carbonic acid and water, presents the DeMartini equations as follows:

(1) OH^- (in terms of $CaCO_3$) $= \dfrac{5\times10^{-10}}{(H^+)}$

(2) $CO^=_3$ (in terms of $CaCO_3$) $= \dfrac{5.61\times10^{-6}}{(H^+)} \times A$

(3) HCO^-_3 (in terms of $CaCO_3$) $= 50{,}000\times A$

(4) CO_2 (as CO_2) $= 3.70\times10^{10}\times(H^+)\times A$

Where A is the factor $\dfrac{\dfrac{T}{50{,}000} + (H^+) - \dfrac{10^{14}}{(H^+)}}{1+\dfrac{11.22\times10^{-11}}{(H^+)}}$

in which T stands for total alkalinity in p.p.m. and (H^+) represents the hydrogen ion concentration in molecules per liter and is related to pH by the expression $pH = \log \dfrac{1}{(H^+)}$

The total alkalinity is an equilibrium mixture of its OH^-, and $CO^=_3$, and HCO_3 components. If the amounts of OH^-, and $CO^=_3$, and HCO^-_3 in a given alkalinity are expressed in terms of percentage of the total alkalinity, any given equilibrium mixture can be represented by a point on a triangular coordinate diagram (see fig. 1). The triangular diagram has three coordinates, the fractional percentages of each of the three alkalinity components, OH^-, $CO^=_3$, and HCO^-_3. These vary from 0 percent at the three sides of the triangle to 100 percent at the opposite apex.

Using Moore's equations, the amounts of OH^-, $CO^=_3$, and HCO^-_3 in equilibrium with each other at pH values ranging from 7.0 to 11.6 for alkalinity values of 25, 50, 75, 100, 150, 200, and 300 p.p.m. were calculated, converted to the fractional percentage basis, and plotted on the triangular diagram. The curves show how the relative proportions of OH^-, $CO^=_3$, and HCO^-_3 for any given alkalinity change with pH. The diagram presents curves for waters with total alkalinities of 25, 50, 75, 100, 150, 200 and

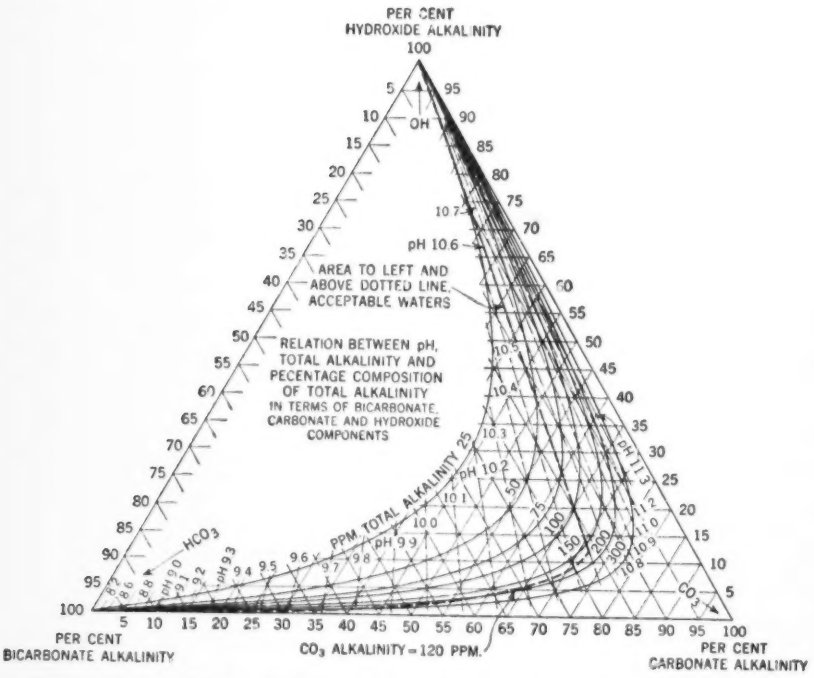

FIGURE 1.—Relation between pH, total alkalinity, and percentage composition of total alkalinity.

300 p.p.m. (heavy solid-line curves). The thin lines running from the base of the triangle to the opposite apex (100 percent OH^-) represent samples of any given pH and show how for any given pH the relative amounts of OH^-, $CO^{=}_3$, and HCO^-_3 will vary with total alkalinity.

The Drinking Water Standards set the following limits:

1. The water shall not have a pH greater than 10.6.
2. The carbonate ($CO^{=}_3$) alkalinity shall not exceed 120 p.p.m.

The thick broken lines represent these limits. All samples whose compositions are represented by points to the left of the 10.6 pH tieline and above the 120 p.p.m. $CO^{=}_3$ line are acceptable. All samples of composition represented by points to the right of and below the limiting lines do not meet the recommended pH and alkalinity standards. The above limits for pH and alkalinity apply to all chemically treated waters, including both lime-soda- and zeolite-softened waters. It should also be understood that

natural waters having a pH and alkalinity below these limits are not desirable as drinking waters.

Because chemical equilibria are affected by changes in temperature and by changes in the ionic strength of the solution, Moore's equations are strictly valid only for waters at 25° C. and low in dissolved-solids concentration. Ionic strength is more or less proportional to dissolved-solids concentration. However, for practical purposes the equations hold quite accurately for all pH values up to 10.0 in waters containing up to 500 p.p.m. dissolved solids at temperatures from 15° to 25° C.

B. BACTERIOLOGICAL

The bacteriological examinations which have come to be recognized generally as of most value in the sanitary examination of water supplies are:

1. The count of total colonies developing from measured portions planted in agar or gelatin plates and incubated for 48 hours at 20° C.

2. A similar count of total colonies developing on agar plates incubated for 24 hours at 37° C.

3. The quantitative estimation of organisms of the coliform group by applying specific tests to multiple portions of measured volume.

Of these three determinations, the test for organisms of the coliform group is almost universally conceded to be the most significant, because it affords the most nearly specific test for the presence of fecal contamination. Only this test has been included, therefore, in the bacteriological standard adopted, as neither the 37° C. nor the 20° C. plate count would appear to add information of sufficient importance, for the purpose of the Standards, to warrant their inclusion in the required examination. The omission of plate counts from the standard is not to be construed as denying, or minimizing, their importance in routine examinations made in connection with the control of water-purification processes.

For the purposes of the Standards, the coliform group is defined as including all organisms considered in the coli-aerogenes group as set forth in Standard Methods for the Examination of Water and Sewage, current edition, as prepared, approved, issued, and published jointly by the American Public Health Association and the American Water Works Association, New York.

In accordance with this definition, the bacteriological standard provides that the procedure required for the demonstration of the

coliform group be as prescribed in Standard Methods, referred to above, for the tests designated:

(a) The completed test, or

(b) the confirmed test, when a liquid confirmatory medium (brilliant-green lactose bile broth, 2-percent) is used, provided the formation of gas in any amount in this mediun. during 48 hours of incubation at 37° C. is considered to constitute a positive confirmed test, or

(c) the confirmed test where (i) crystal-violet lactose broth, (ii) fuchsin lactose broth, or (iii) formate ricinoleate broth are used; providing the worker demonstrates the conformance of results, obtained with these three media, to the required conditions.

Moreover, it is recommended that this reference to Standard Methods shall be considered as applicable to all details of technique, including the selection and preparation of apparatus and culture media: the collection and handling of samples; and allowable intervals between collection and examination. As the standard procedure cited in this reference does not require differentiation between the various forms or types which are included under the general definition of the coliform group as given above, it has not seemed advisable, in the present state of knowledge, to require such differentiation in the application of the bacteriological standard. Two considerations tend to militate against the necessity or propriety of complicating the bacteriological standard by the incorporation of such differentiation. First, an analysis of the records of a considerable number of municipal water supplies during the past 20 years suggests that the coliform group has served effectively as an indicator of fecal pollution when the procedure for the determination of the coliform group was carried out in exact accordance with the methods specified. Second, competent research findings indicate that all constituent members of the coliform group are usually found in human fecal material. Consequently, it seems advisable to emphasize here a strict observance of the methods referred to, rather than to introduce any unnecessary procedures for the differentiation of the coliform group.

The principles involved in the quantitative interpretation of fermentation tests according to the "most probable number" concept, in multiple portions of equal volume and in portions constituting a geometric series, were discussed fully in appendix III of the Standards promulgated in 1925*(15)* and since then this discussion has been amplified by various authors. As these principles are not understood universally, and enumeration procedures concerned are used quite widely, it has not appeared necessary to repeat this discussion in the current revision. The testing of

multiple portions of equal volume affords a more precise measure of the density of the coliform group within a relatively narrow range of variation than does the testing of portions in geometric series. Therefore, as the waters which will be offered for certification should represent only a narrow range of very moderate pollution, the bacteriological standard requires that the examination of each sample shall consist of the separate testing of five equal portions either of 10 ml. or of 100 ml. each.[3] For laboratories which are equipped to make such tests, the examination of the larger, 100 ml., portions provides for:

1. A more definitive measure of the density of coliforms in the range of about one per 100 ml., as established by the bacteriological standard.

2. Information as to the approach of unfavorable conditions in the water.

The procedure for the examination of 100-ml. portions offers no difficulty in laboratory technique, the only additional requirements being larger containers, larger quantities of media, slightly greater incubator space and the collection of a larger sample. If economy of incubator space is desirable, multiple-strength lactose broth may be used in conformity with the provisions in "Standard Methods for the Examination of Water and Sewage." In practice, it has been found satisfactory to use standard dilution water bottles of 160–180-ml. capacity as tubes or containers for the 100-ml. portions. These bottles, containing 30–35 ml. of quadruple-strength lactose broth and equipped with the ordinary inverted vial or with a Cowles *(14)* tube, are sterilized in the usual manner. For convenience in checking volumes, or to eliminate the necessity for the use of volumetric pipettes, the bottles may be graduated at the 35-ml. and at the 135-ml. points. This procedure lends itself readily to the planting of samples directly into lactose broth at the site of collection of the samples.

There is, of course, no essential reason why the number of portions tested should be five, rather than some larger number, except that it is necessary to limit the labor and materials required, and five portions are considered sufficient for such precision as is ordinarily required.

With reference to the total number of samples which should be examined, the intervals at which they should be collected, and

[3] It is advisable, especially in the examination of waters of unknown quality, or which may be suspected to be highly polluted, to make simultaneous tests in portions of a geometic series, ranging from 100 ml. to 1.0 ml. or less.

the location of the sampling points on the distribution system, it is recognized that such requirements are affected by:

1. The nature of the source of the water.
2. The character and the consistency of the treatment provided.
3. The sanitary conditions of the distribution system.
4. The average daily volume of water delivered to the distribution system.
5. The total population served.

It is obviously desirable from the standpoint of precision and significance of results to examine a large number of samples collected at frequent and regular intervals, and when normal conditions obtain, preferably at uniformly spaced points on the distribution system, but when abnormal conditions exist, at such points as will produce the maximum information concerning the cause of any abnormalities in water quality. It is obvious also that it is not practicable to lay down hard and fast requirements adapted to the qualities of each supply in question. It has appeared desirable, however, to establish for the ideal supply the minimum number of samples to be collected and examined during specified intervals, based on the population served, and to delegate to the inspecting officer, who should have knowledge of the conditions affecting the supply in question, the authority to increase the number of samples required and to fix the times and the sites for the collection of samples on the distribution system.

The location of sampling points should be selected with care so that a true evaluation of the average condition of the water in the distribution system may be obtained. In evaluating any water supply with respect to a sampling schedule, consideration should be given to the individual circumstances and extent of efforts being made to achieve the recommended schedule.

In accordance with these principles, the first requirement stated in the bacteriological standard, namely, that "of all the standard 100-ml. or 10-ml. portions examined per month in accordance with the specified procedure, not more than 60 percent or 10 percent, respectively, shall show the presence of organisms of the coliform group," may be interpreted as implying that the mean density of organisms of the coliform group shall not exceed about 1 per 100 ml. The second clause of the standard, which specifies that not more than 20 percent (or 5 percent when 10-ml. portions are examined) of the samples tested (or not more than 1 sample if the whole number tested is less than 20 for 10-ml. portions or less than 5 for 100-ml. portions) shall show the pres-

ence of organisms of the coliform group in all 5 100-ml. portions, or in 3 or more of the 5 10-ml. portions, is more complex in its implications and more difficult to explain. This requirement was ably discussed in appendix III of the 1925 Standard *(15)*, and this discussion has been amplified by various authors since that time. It has been recognized that, according to the laws of chance, the presence of coliforms in the above-mentioned amounts would occur in a certain small proportion of the samples tested, even though the mean density of organisms of the coliform group in the whole body of water tested actually remains constant at about 1 per 100 ml. or less, and consequently, that it warrants no inference of actual fluctuations in density unless it occurs with greater frequency than would be expected according to the theory of chance occurrences. A more frequent occurrence, sufficient to indicate an occasionally higher pollution, is believed, however, to be an indication of potential danger, even though the average quality of the water should be satisfactory, that is, in conformity to the first provision of the bacteriological standard. This clause of the standard undertakes to set a limit to the allowable frequency of positive results in an increased number of portions of any sample. It is necessary in doing this to recognize that water supplies actually do vary in their degree of pollution from day to day, and that in many instances the series of tests which are considered may be small; hence, the limit (20 and 5 percent) is set at a frequency which is higher than reasonably might be expected in a large series of samples from a water in which the actual density of organisms of the coliform group never greatly exceeds 1 per 100 ml. In the case of 10-ml. portions, the limit for this frequency is set at 5 percent, which is approximately five times higher than the normal expectancy. With 100-ml. portions, the requirement is somewhat more stringent, as the 20 percent frequency allowed is only about 2.5 times higher than might be reasonably expected. As the possibility of an increase in pollution is ever present, the bacteriological standard provides further that when positive results are obtained in increased numbers of portions of any sample, additional and more frequent samples shall be collected and examined. The results from such additional samples will demonstrate whether the increase in positive results is due first to the probabilities of chance, or second to an actual increase in density of pollution.

In the bacteriological standard which has been promulgated, the committee has undertaken to set up two controlling factors. First, two limiting values of the density of organisms of the coliform

group, one limit applying to the mean density as calculated from the entire series of tests made during any one month and one to the range and frequency of occasional deviations from this mean, and second, a requirement for conformance with the specified procedures for making the bacteriological examinations concerned. Failure to conform with the specified procedures may be used as a basis for considering a supply unsatisfactory. That is, a failure to follow the specied procedures might produce results which would not provide a satisfactory opinion of the quality of the water supply concerned.

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